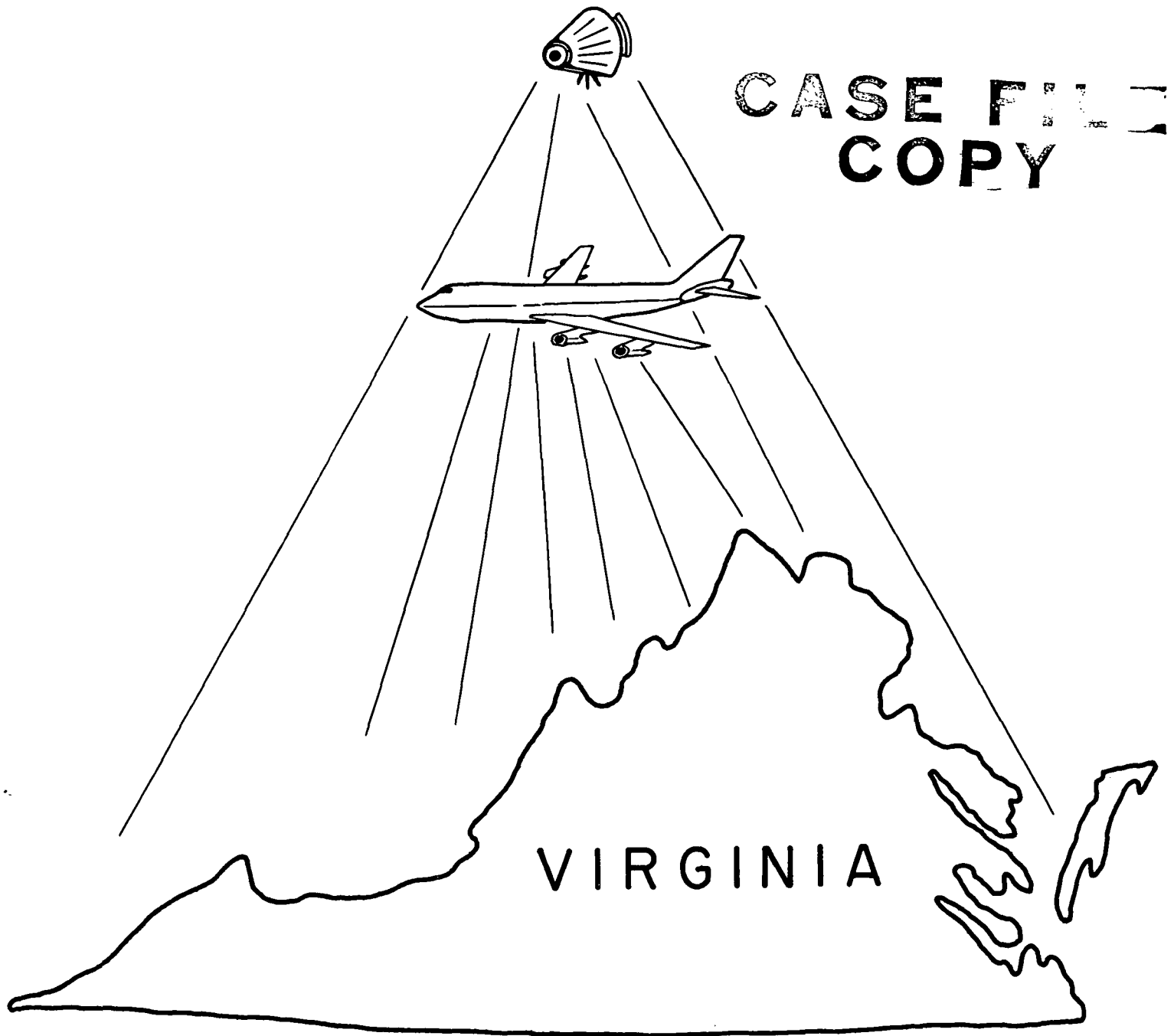


REMOTE SENSING IN VIRGINIA AGRICULTURE

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Research Division Report 71

Virginia Polytechnic Institute and State University
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A cooperative research project of remote sensing in agriculture was initiated in July 1970 by the Agronomy Department of Virginia Tech, the National Aeronautics and Space Administration, Wallops Island, Virginia, and the Virginia Truck and Ornamentals Research Station, Painter, Virginia. Initial objectives and methodology were designed to develop and evaluate multispectral sensing techniques for the detection of plant species and associated diseases, soil variations, and cultural practices under natural environmental conditions.

The term remote sensing is somewhat vague, but it generally means viewing or gathering information about an object or condition from some distance without coming into physical contact with that object. A photographic snapshot of a subject from a few feet away, or an image of the earth recorded from outer space are both a part of remote sensing. Conventional aerial photographs have been used in agriculture for several decades as base maps for soil surveys, measurement of crop allotments, design of drawings and irrigation systems, and other direct uses. Recent technological advancements, many resulting from space research, have opened new horizons in agricultural research. Remote sensing may be separated into photographic and non-photographic operations.

PHOTOGRAPHIC SENSING—The recent development and refinement of aerial infrared (IR) film have contributed greatly to the field of remote sensing. Unlike conventional color film, which has layers sensitive to blue, green, and red radiation, the infrared film has the blue layer replaced by an infrared sensitive cyanic layer (2). All three layers are sensitive to blue light which is usually filtered out with a yellow filter. Conventional black and white and color films have a sensitivity range from about 0.36 to 0.72 micrometers, which is similar to the detection range of the human eye (5). Infrared color film used with

a yellow filter has a sensitivity range of about 0.52 to 0.92 micrometers, while black and white infrared film may extend to about 1 micrometer (14). The use of infrared film extends the visual detection range considerably. Parts of the spectra that were previously beyond visual detection may now be viewed, measured, and studied. This capability of extending the normal visual range was utilized in World War II with the newly developed aerial infrared film, which was commonly referred to as camouflage film (3). Infrared film depicted normal vegetation as bright red, while camouflage materials appeared blue.

NON-PHOTOGRAPHIC SENSING—Non-photographic sensing, or more correctly, imaging, has developed rapidly in the past decade. Unlike photographic techniques which rely strictly on differences in reflected radiation, some types of non-photographic sensors use their own light source, or record reradiated heat at specific wavelengths (6). These devices can be constructed to scan the target area, and their output can be displayed as an image of the scene.

For the ultraviolet region of the spectrum, scanners may be constructed that are sensitive to very short wavelengths. However, because the atmosphere is opaque below about 0.3 micrometers, ultraviolet scanning is done by detecting the reflected radiation in the spectral interval from about 0.3 to 0.4 micrometers. The detector is typically a photomultiplier tube in which the incoming photons cause electrons to be emitted by a photosensitive surface. The electrons are multiplied through secondary emission, and ultimately they are collected at the anode where the resulting electrical signal is proportional to the intensity of the incident radiation. These electrical signals may then modulate a light beam to produce, point by point, an image on film of the scene as the detector sees it; or the signals can be stored on tape to be analyzed by computer.

Visible scanning systems are similar to the ultraviolet systems. The detectors are sensitive to reflected radiation in the 0.38 to 0.78 micrometers wavelength region. These systems normally need clear, daylight conditions to function properly.

Infrared scanners record both reflected radiation and heat given off by a body, and they can function properly in light or darkness. These detectors operate on principles similar to the ultraviolet and visible scanners. However, cooled

¹ This work supported by a research grant from the National Aeronautics and Space Administration—Wallops Island Station, Virginia (NASA Contract No. NAS 6-1863.)

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solid state detectors are used, and free charged carriers produce images at wavelengths of 0.78 to 14.0 micrometers(4).

Microwave techniques have been employed to record longer wavelengths from 0.5 mm to 1 meter. These systems are less hampered by clouds and rain than the previous systems(4). However, the small amount of energy emitted by a target in the passive system and the large amount of energy required in the active system inhibits its use from extremely high altitudes.

Remote Sensing in Agriculture—Many plants are adapted to reflect a high percentage of radiation in the infrared region which prevents them from becoming too warm. These reflective and some emissive properties of plants and soils are conducive to remote sensing studies. Previsual detection of plant diseases and nutrient deficiencies by remote sensing techniques, before these conditions can be observed on the ground, has considerable potential.

Manzer and Cooper(8) compared conventional aerial color, panchromatic films, and infrared films for identifying areas of severe defoliation from late potato blight. Only severe defoliation was detected on conventional film, but color infrared film showed disease symptoms 1 to 3 days before they became evident on the ground. Diseases of beans were identified by Philpotts and Wallen(12) using infrared film. Remote sensing systems employing helicopters and infrared films have been used in Florida for disease detection and spreading decline in citrus(11), thus reducing the frequency of costly time consuming ground surveys.

Remote sensing is also being used in forestry. Meyer and French(9) used color infrared film and fixed-wing aircraft to detect Dutch elm disease in Minnesota. Nubert(10) used infrared scanners to detect diseased trees. Diseased trees have restricted capacity to accumulate water for transpiration. The reduced transpiration rate results in temperature differences of 3 to 5°C between healthy and diseased trees.

Soil differences may also be detected by remote sensing. Workers at Purdue University(13) made flights over two varying soil types employing multispectral photography and thermal infrared scanners. The information contained in the visible and near infrared photographs was similar, but the dark colored soil adsorbed more radiation and temperature differences showed up on the thermal scanner. Condit(1) reported that wet soils reflect two to three times the radiation of dry soils at wavelengths between 0.6-1 micrometers. Khul(7) attempted to identify soils and drainage patterns by multi-spectral photography with variable results.

METHODS AND MATERIALS

The primary research site is located 26 miles south of the NASA-Wallops Island Station at the Virginia Truck and Ornamentals Experiment Station at Painter, Virginia.

The 100-acre experimental farm is conveniently arranged in rectangular fields which enhances the task of photographic analysis. The farm is located in an intensive vegetable crop and ornamental production area. It is situated on typical soils of the area which have extensive acreage. Excellent ground control and detailed records of previous practices have been maintained for the farm.

Soils—A detailed soil survey was made of the research farm. Laboratory analyses of typifying soil pedons were conducted to establish the soils' physical, chemical, and mineralogical parameters. Sassafras soils comprised the dominant acreage of the research site. These are deep, brown, sandy soils that have developed in moderately coarse-textured marine sediments of the lower Coastal Plain. These soils are strongly acid, low to medium in inherent fertility, and low in organic matter content. Quartz is the dominant mineral component of the sand fractions. The silt fractions are also dominated by quartz, with lesser amounts of kaolinite, interlayered vermiculite, and iron oxides. Clay fractions are comprised dominantly of kaolinite, interlayered vermiculite, quartz and iron oxides. The sand contents of the surface horizons range from 50 to 70%, with 25 to 44% silt, and 4 to 9% clay. Maximum clay contents range to 40% in subsurface B horizons, with average values of 30%. A sharp decrease in silt and clay content occurs at depths below 50 inches, which is accompanied by an increase in sand content. The very sandy layer extends to depths of 90 inches and greater.

Overflights—Photographic overflights of the research site have been made by helicopters at altitudes from 500 to 10,000 feet. A T-11 camera system with 9-inch-square format, and 4 channel film capability was used. The camera system can take color, black and white, and infrared color and black and white photographs synchronously. Kodak color aerial infrared Ektachrome #2443 with a Wratten #12 Filter and infrared black and white #2424 film with a Wratten #25A filter have been used extensively. Flight lines and times were designed for maximum consistency and minimum interference from environmental variables. Various film, filter, and shutter-speed combinations are being used and evaluated.

Environmental Data—A system has been installed at the research site to continuously monitor environmental factors that influence the remote sensing. Solar radiation, an important variable, is continuously monitored as are air, soil, and plant temperature, relative humidity, and wind speed and direction. The data are recorded on a multichannel recorder housed in an instrument building near the center of the research site.

Ground Truth Data—In addition to recording environmental variables, the crop species, varieties, age, spacing, plant height, percentage ground cover, and plant vigor are de-

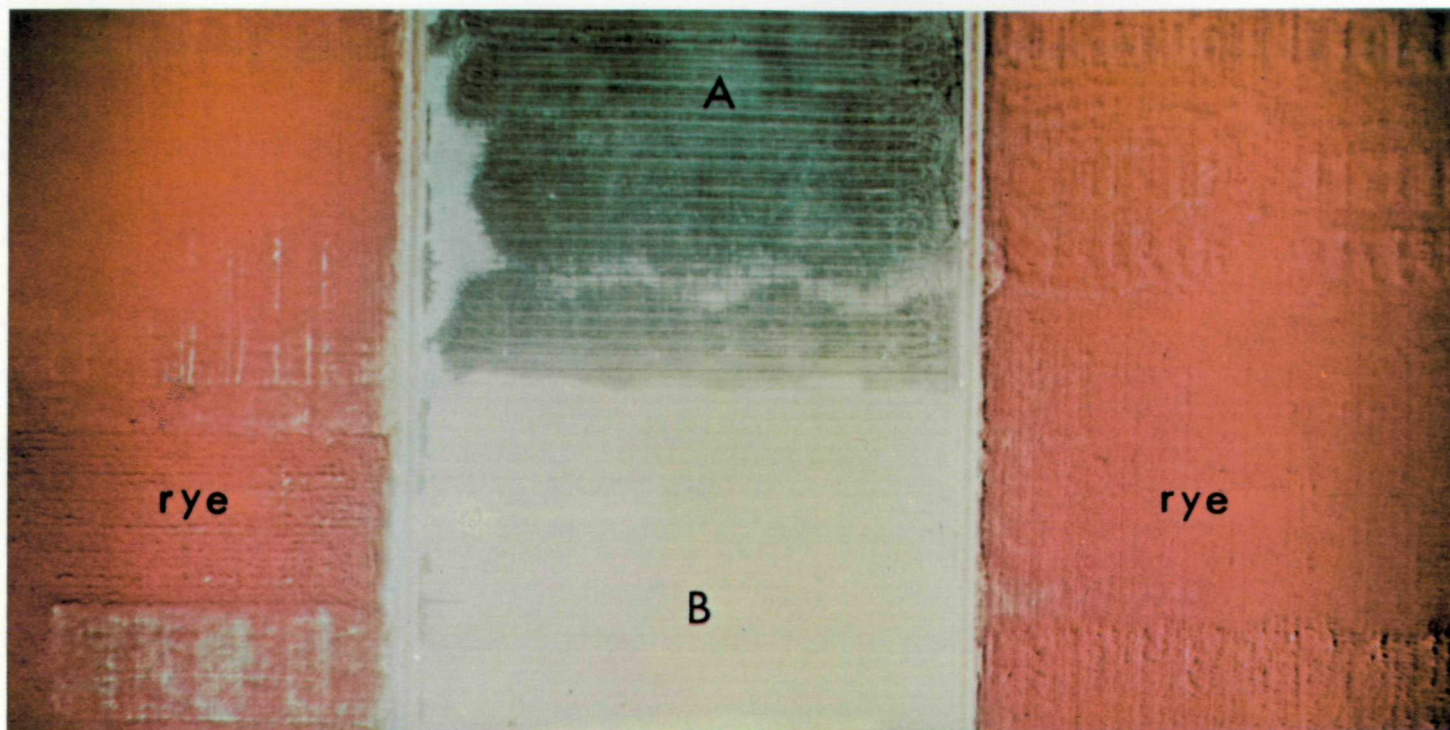


Photo 1—Aerial Ektachrome infrared photograph taken at 500 feet altitude showing the contrast in soil moisture levels. Natural green colors in the field appear as shades of red in the infrared photograph.



Photo 2—Aerial Ektachrome infrared photograph taken at 10,000 feet altitude showing the variations in soil moisture and organic matter levels.

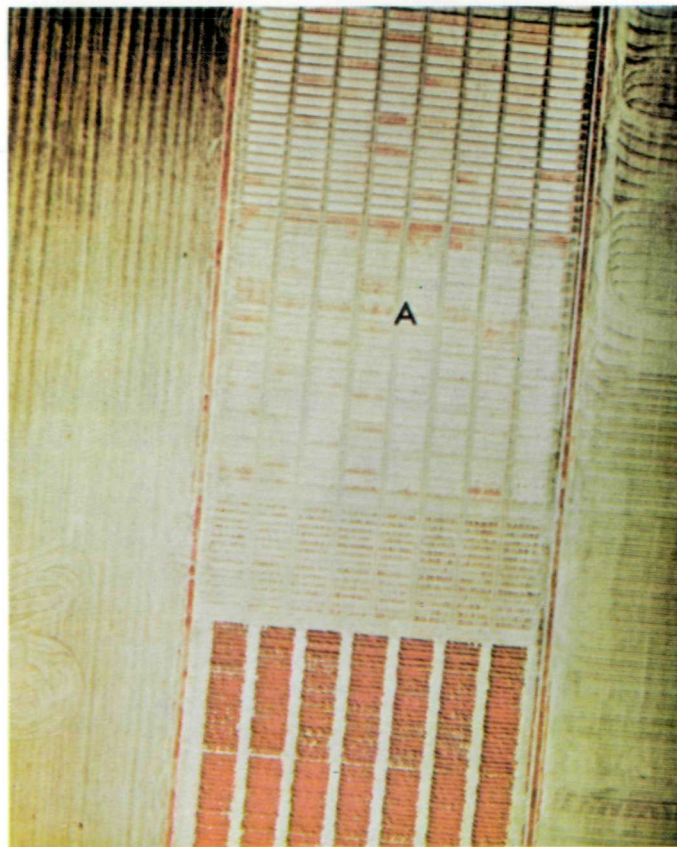


Photo 3—Aerial Ektachrome infrared photograph taken at 500 feet altitude showing the effects of herbicide treatments.

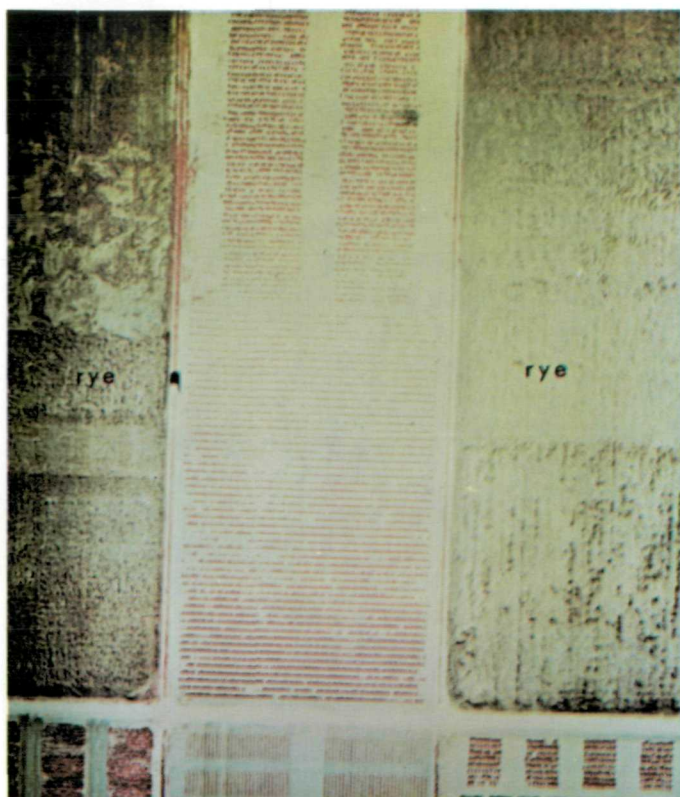


Photo 4—Aerial Ektachrome infrared photograph taken at 500 feet altitude showing mature rye fields.

terminated for each overflight. Leaf samples are also collected from specific fields for chlorophyll determination, percentage of moisture, and reflection measurements. Soil variables are also measured. These include soil moisture, color, consistency, surface condition, and organic matter content.

DISCUSSION

Remote sensing overflights during various stages of the growing season revealed several striking features. Lush green vegetation shows up as various shades of red or red-dish-purple in the color infrared photographs, whereas plants exhibiting pronounced chlorosis generally appear in shades of yellow or gray.

Marked variations in color are evident between irrigated and non-irrigated fields on the color infrared photographs (Photo 1). Section (A) of the central field in Photo 1 has a high moisture content (15%) and it appears blue; while the other Section (B), at a low moisture content (2%), appears much brighter. Circular moisture patterns are evident (Field A) where the irrigation water has not diffused evenly in the soil. Preliminary results indicate that

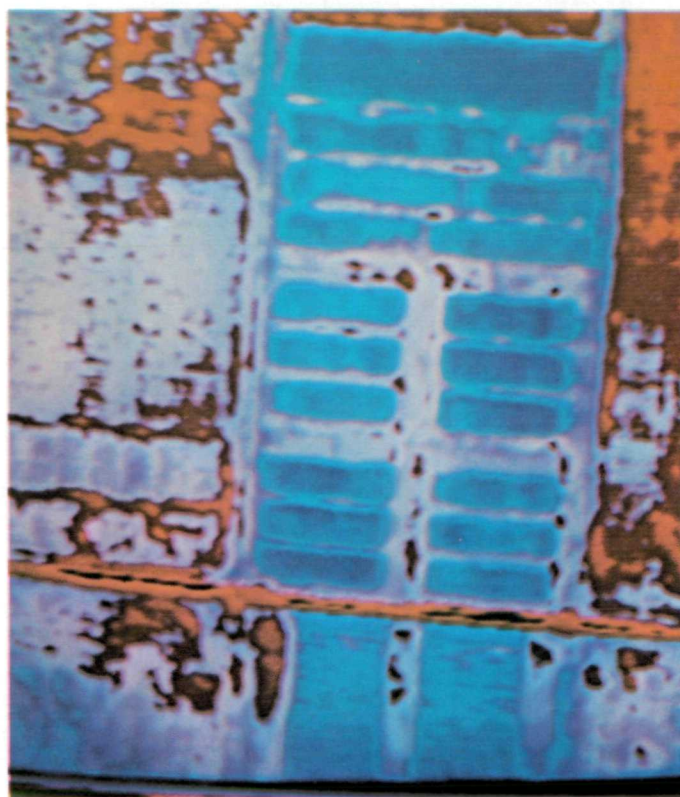


Photo 5—Photograph showing different density levels of an infrared photograph as displayed by an iso-densitometer instrument. The density tablet at the bottom of the photo enables assignment of density values to each color.

an increase of 100% in reflection between a wet soil and a dry soil may commonly occur in bare siliceous soils. Differences in soil moisture and organic matter contents are also evident from an altitude of 10,000 feet (Photo 2). Variations in the lightness and darkness of the bare soil areas reflect differences in soil moisture and organic matter levels. The lighter colored areas have lower soil moisture and organic matter contents. At lower organic matter content, more mineral particles are exposed which result in increased reflection.

Evaluations indicate that bare soils and areas containing vegetable crop species with very small leaf area are quite similar on color infrared photographs taken at altitudes of 500 feet and greater. Leaf area and plant height appear to affect the reflection of visible and infrared radiation. Generally, young vegetable crop species with less than 10% leaf area appear very similar to bare soil areas. These plant characteristics are useful in efforts to establish spectral "signatures" for various crop species by remote sensing. Similarly, nutrient deficiencies, or other factors which reduce plant leaf area, may be detected during early stages by remote sensing.

The effects of herbicide treatments are readily distinguishable in the infrared region (Photo 3). The red plots in Field A indicate herbicide treatments which failed, and the resultant green vegetation appears red in the infrared photograph. Bare soil plots in Field A reveal where the herbicide treatment eliminated weed competition. From the air the extent of the effective herbicide treatments is clearly indicated by the distinct boundaries. Initial results suggest that greater accuracy than is normally achieved in the field observations for such aerial measurements may be obtained utilizing color infrared photographs.

Differences in crop maturity are apparent in color infrared photographs taken at various time intervals. For example, the luxuriant rye in full growth appears red in the spring (Photo 1). By early summer, the mature rye leaves have lost their reflective properties and the field appears brown and yellow (Photo 4).

Integration of the aerial infrared photographs, ground truth, and environmental data have produced interesting and often unexpected results. Differences in solar radiation intensities, soil moisture, percentage of plant coverage, and plant nutrition have been noted to produce variation in photographic colors and intensities. Similarly, photographic procedures involving film-filter combinations, film emulsions, and development techniques produce variations in photographic images and color intensities.

Various film and filter combinations have been employed to enhance the sensitivity of a particular part of the spectra. The spectral transmission curves, illustrated in Figure 1, indicate the general theoretical responses of the color infrared film used in this project. A CC20M filter has been employed with success on occasions to enhance the bare soil areas for intensive evaluations. The effects of this film-filter combination are illustrated in Figure 2.

Considerable difficulty was experienced in photographic evaluations of earlier overflights. Center portions of the color infrared photographs were consistently brighter than the outer portions. This radial decrease in exposure or vignetting greatly complicates tone analysis. This problem was solved by the use of an anti-vignetting filter. The filter reduces the amount of light striking the center of the film thereby producing a more uniform exposure. Earlier workers may easily have mistaken the vignette effects as soil-plant phenomena.

The photographs are evaluated using the Munsell color system and optical density measurements. These techniques permit the photographs to be coded into a numerical arrangement which is compatible for statistical study and computer storage. The results of a density evaluation of a color infrared photograph using an isodensitometer are illustrated in Photo 5. This instrument color codes areas on a photograph with similar density levels and it displays them on a television monitor. Thirty-two color choices allow the se-

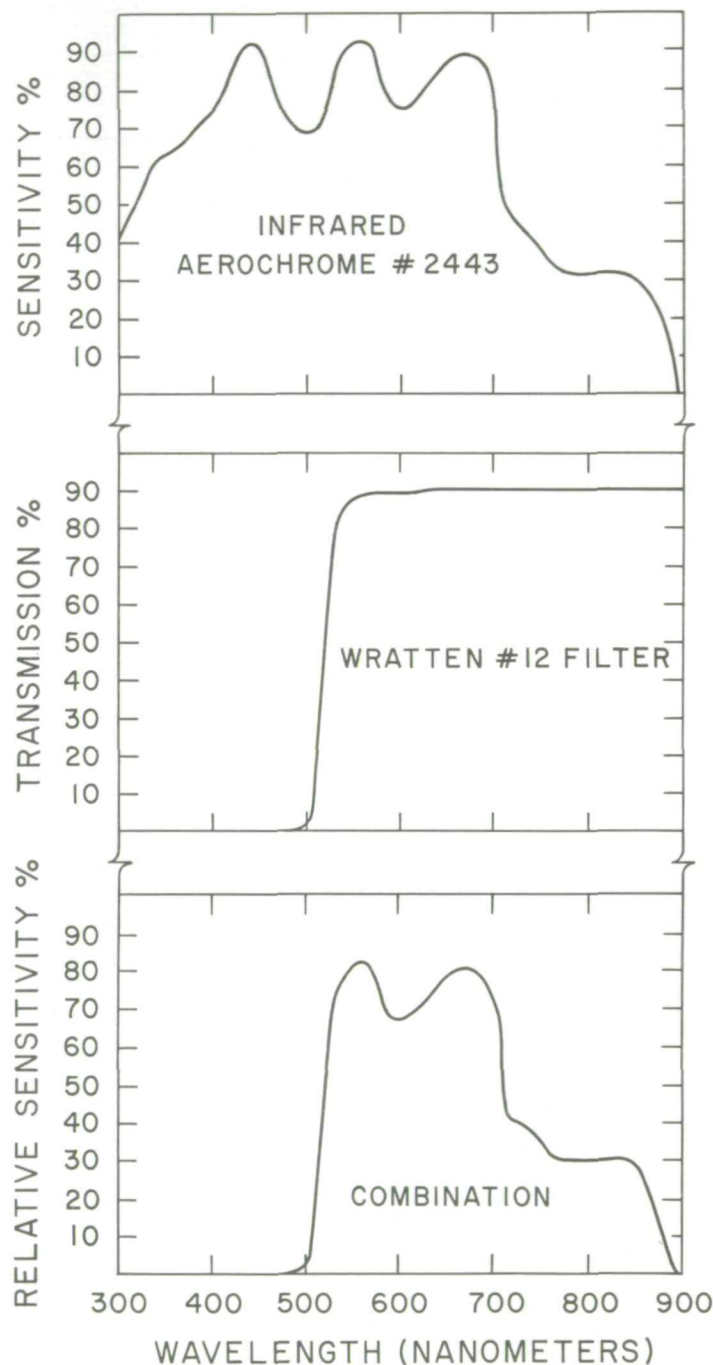


FIGURE 1.—Representative theoretical spectral transmission curves for aerial Ektachrome #2443 infrared film and a Wratten #12 filter. (Reproduced Courtesy NA SA-Wallops Island Station)

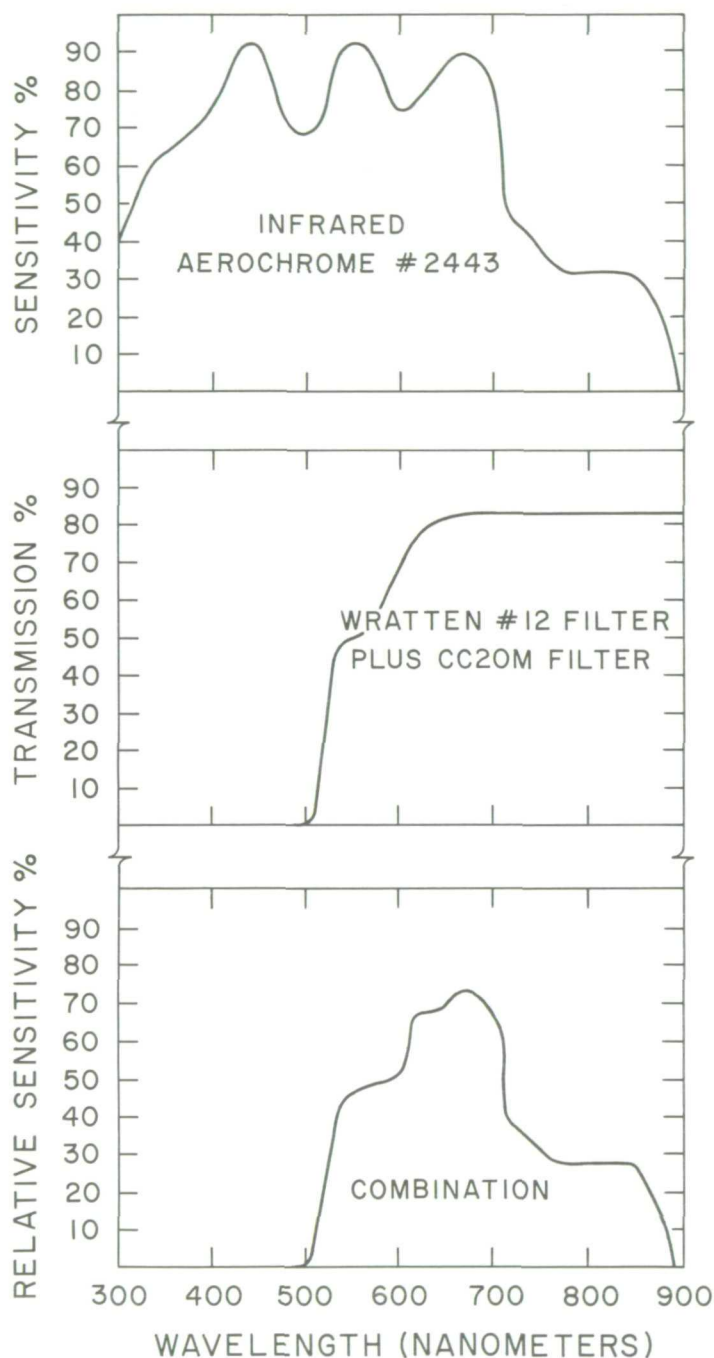


FIGURE 2.—Representative theoretical spectral transmission curves for aerial Ektachrome #2443 infrared film, a Wratten #12 and CC20M filters. (Reproduced Courtesy NASA-Wallops Island Station)

lection of colors which provide the greatest contrast between density values. The use of a density step tablet permits aerial numerical measurements with the isodensitometer. Conventional densitometers provide numerical optical density measurements of the photographs. Initial efforts have been directed to digitalize the remote sensing and ground truth data for computer storage and recall.

Future remote sensing flights will utilize fixed-wing aircraft employing both aerial photography and infrared scanners. The scanner data will complement the photographic techniques and greatly extend the investigations to longer wavelength energy ranges.

Improved remote sensing techniques and equipment combined with data processing are opening new horizons in agricultural research. Detailed natural inventories of remote inaccessible areas may be accomplished economically and rapidly in the near future via remote sensing. Entire new areas of agricultural research are being opened by this modern technology. Dramatic advances may occur as the total overall view becomes available to the researcher, and in time, the role of the component fractions may be studied through remote sensing.

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